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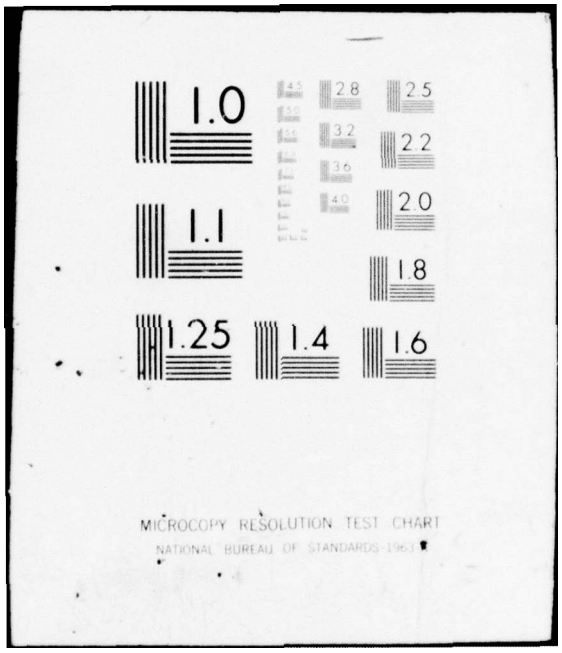
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DREO TECHNICAL NOTE NO. 76-23
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# A PHYSIOLOGICAL COMPARISON OF TWO TYPES OF DUFFEL SOCK FOR USE WITH THE CANADIAN FORCES MUKLUK

by

S.W. Nolan, P.V. Vittoria and S.W. Cottrell



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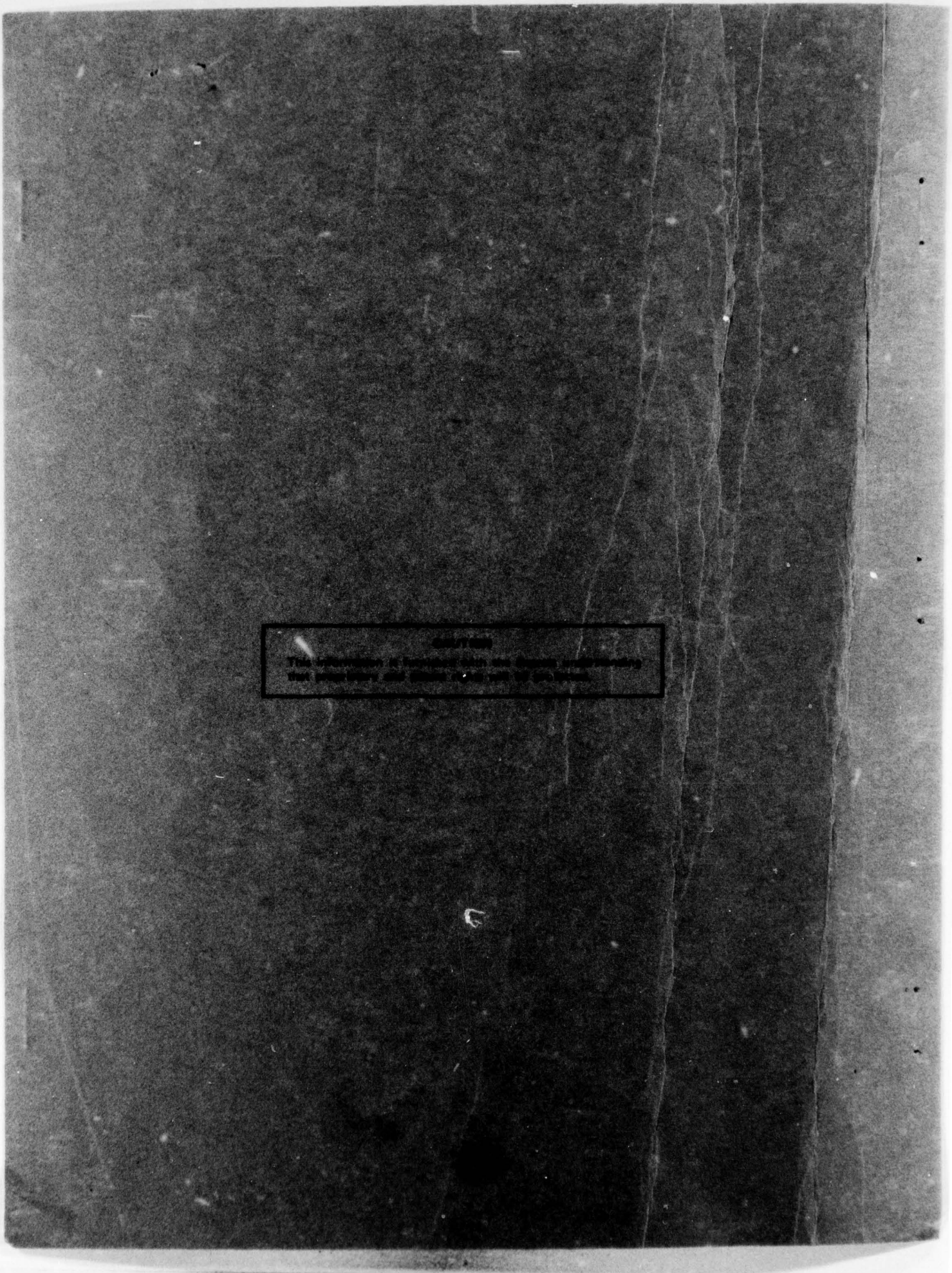

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# A PHYSIOLOGICAL COMPARISON OF TWO TYPES OF DUFFEL SOCK FOR USE WITH THE CANADIAN FORCES MUKLUK.

by

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## ABSTRACT

A series of physiological trials was conducted in the DREO cold chamber to compare the durability, comfort and thermal protection offered by the standard Canadian Forces duffel sock and an experimental duffel sock worn with the Arctic mukluk. No significant differences in levels of foot perspiration or foot temperature were observed. However, since the correct sizes were not available, none of the test subjects could be fitted properly with the experimental duffel sock and varying degrees of foot discomfort were experienced.



## RÉSUMÉ

On a procédé a'une série d'expériences physiologiques dans la chambre froide de CRDO pour comparer la durabilité, confort et protection calorifique fourni par les chaussettes de molleton réglementaires des Forces Canadiennes à des chaussettes de molleton expérimentaux qui est porté avec des bottes mukluk. Il n'existe donc aucune différence apprèciable à niveaux de sudation des pieds ou de température. Cependant, les pointures correctes n'etaient pas disponsible et par conséquent aucun des sujets des épreuves ne pouvait pas être bien adapté avec les chaussettes de molleton expérimentaux et les sujets ont éprouvé divers degrés de malaise des pieds.

## INTRODUCTION

The standard footwear used by the Canadian Forces when operating in Northern or Arctic regions under extreme cold dry conditions is the Cold Weather Footwear System or Mukluk Assembly (Figure 1). This system consists of a mukluk, a duffel sock and two insoles, with each item being dependent upon the other for effectiveness. A more complete description of each of the components is given below. One of the more important components of the mukluk assembly is the thick woollen duffel sock which is designed to provide thermal insulation for the foot and is able to absorb relatively large amounts of moisture resulting from foot perspiration. In addition to thermal protection, the thickness of the material cushions the foot inside the mukluk and provides physical protection and comfort.

As a result of difficulties in obtaining the specified duffel sock material in Canada, the footwear manufacturer submitted a sample of two pairs of experimental duffel socks (labelled B-429) made of a slightly different material than that used for the standard sock. The cloth used was 75% wool/25% nylon and 1.1 kg $m^{-2}$ (31 oz. $yd^{-2}$) versus the specified "at least 80% wool and no more than 20% viscose, 0.93 kg $m^{-2}$ (27.5 oz. $yd^{-2}$)", in the standard issue sock. It was requested that physiological tests be conducted to determine whether the durability, comfort and thermal protection offered by the experimental socks were comparable to those of the standard sock (1).

## DESCRIPTION OF MUKLUK ASSEMBLY

The Canadian Forces Cold-Weather Footwear System shown in Figure 1 consists of four separate components: the mukluk, a duffel sock, a plastic insole and felt insole (2). Full sizes from 4 to 12 inclusive are available in narrow and medium widths. The CF standard issue grey woollen sock is usually worn on the foot in addition to the above components.

The overall height of the mukluk ranges from 34 cm to 42 cm. The uppers are manufactured from a white polyester fabric 0.30 kg $m^{-2}$ (8.75 oz. $yd^{-2}$). The outsole, heel and bottom reinforcing components are manufactured from a white synthetic rubber compound which meets low-temperature requirements. Instep closure is effected through the use of six "D" rings and nylon laces. The top of the boot is closed by the use of a nylon drawstring. The rubber sole and reinforcing components are vulcanized to the upper under a differential pressure cure system.

The plastic insole is manufactured from a polyvinylidene chloride mono-filament material which is woven into a plain weave for the outer and middle layers and a honeycomb weave for the two inner layers. The outer edges of the insole are fused together by heat sealing and then bound with a white bias binding which is stitched in place.

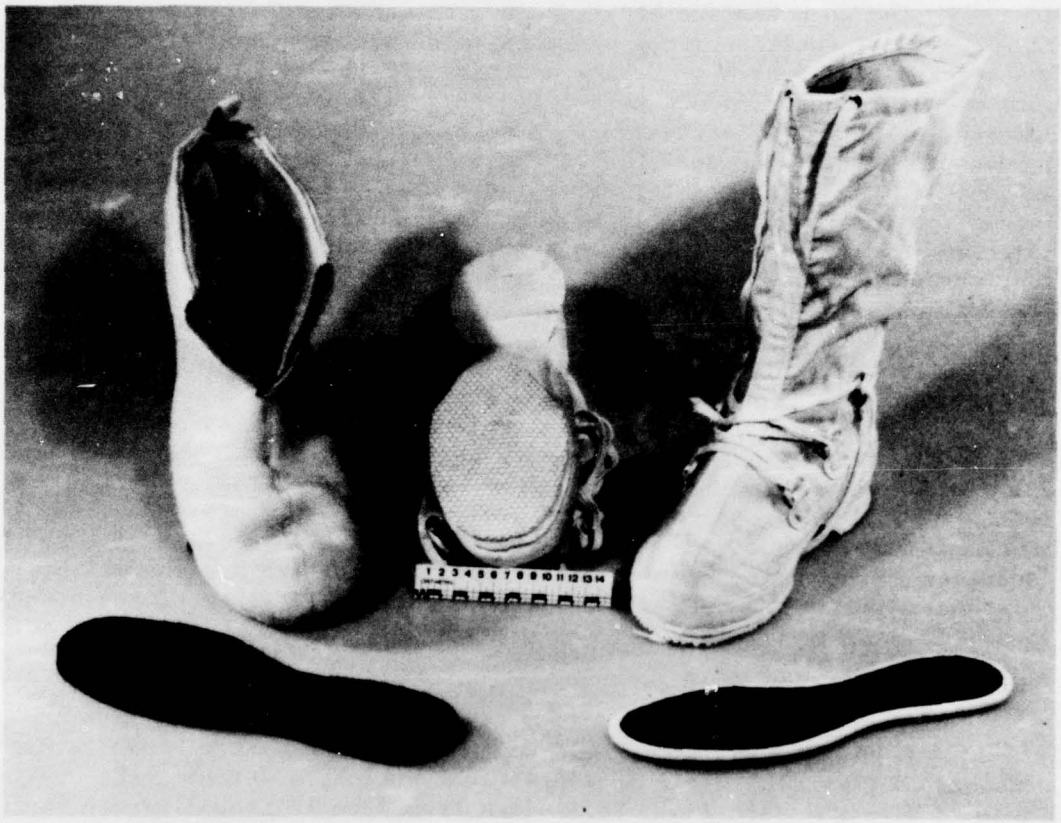

*Fig. 1 - The Canadian Forces Cold-Weather Footwear System*

The felt insole is cut from 12.7-mm felt material containing a mixture of 50% wool and 50% cattle hair.

The standard duffel sock is manufactured from a wool/viscose (0.93 kg $m^{-2}$) duffel cloth with the heel and toe reinforced with nylon fabric. Two layers of material are used in the construction. All edges of the sock material are blanket stitched and the seam closing is serged. A pulltab is provided at the back of the sock. With the exception of the different material used (wool/nylon, 1.1 kg $m^{-2}$), the construction of the experimental duffel sock was similar to that of the standard sock. During the comparative evaluation described in this report, each of the two types of duffel sock was worn in conjunction with the remainder of the standard components of the CF cold weather footwear system.

A comparison of some of the properties of each type of duffel sock is made in Table I. The thickness of single layers of the material used in each type of duffel sock was measured at several different locations and at various pressures using an Aminco compressometer fitted with a 3.18-cm (1.25-in)-diameter foot. Weight per unit area given in the table is that quoted by the manufacturer. Mean total weight was determined by weighing the four experimental duffel socks and four corresponding standard duffel socks.

TABLE I

Physical Properties of Duffel Socks

| Property | Standard Sock | Experimental Sock | Units | Difference (percent) |
|---|---|---|---|---|
| Mean thickness | | | | |
| at 0.07 kPa (0.01 psi) | 7.01 | 9.86 | mm | 40.7 |
| 3.45 kPa (0.50 psi) | 5.87 | 8.13 | mm | 38.5 |
| 6.90 kPa (1.00 psi) | 5.18 | 7.11 | mm | 37.3 |
| Fabric weight | 1.1 | 0.93 | kg $m^{-2}$ | 18.3 |
| Mean total weight | 398 | 333 | g | 19.5 |

## METHOD OF TEST

### Subjects

Four members of the CF/DREO Test Team participated in the evaluation. They were young, male, active military personnel and ranged in age from 0.66 to 0.88 gigaseconds (21 to 28 years). Their physical characteristics are given in Table II.

TABLE II

Physical Characteristics of the Test Subjects

| Subject No. | Age (Gs) | Age (years) | Body Weight (kg) | Height (cm) | Boot Size |
|---|---|---|---|---|---|
| 1 | 0.85 | 27 | 93.7 | 177 | 9 |
| 2 | 0.76 | 24 | 73.3 | 173 | 8 |
| 3 | 0.66 | 21 | 65.8 | 167 | 8 |
| 4 | 0.88 | 28 | 94.5 | 184 | 10 |

Clothing Worn

The following items of Arctic clothing were worn by each of the test subjects during the trial (Figure 2).

- thermal underwear
- CF combat uniform
- CF parka
- windpants
- woollen scarf and toque
- CF Arctic mittens
- grey woollen socks
- standard and experimental duffel socks
- mukluks

Several difficulties were experienced in fitting the test subjects with the experimental duffel sock which was available only in size 9. Due to the extra thickness of the material used in the experimental sock (Table I) when the size 9 duffel sock was placed inside a size 9 mukluk a three-centimetre-high ridge was formed near the arch of the sock. It was found that the experimental duffel sock could be worn without ridging inside a size 10 mukluk.

*Fig. 2 - Test Subject Dressed in Canadian Forces Arctic Clothing*

Subject 4, who normally wears a size 10 boot (Table II) felt slight discomfort when he wore the size 9 duffel sock with his normal mukluk but aside from this, was the easiest test subject to fit.

Subject 1, who normally wears a size 9 boot, was able to obtain a good fit on one foot wearing the size 9 duffel inside a size 10 mukluk but felt that the mukluk on his opposite foot (a standard duffel inside a size 10 mukluk) was uncomfortably loose when he walked. This problem was overcome by using an additional insole inside the mukluk with the standard duffel sock. It should be noted that it was necessary for the test subjects to wear mukluks of the same size on opposite feet during the evaluation.

Subjects 2 and 3, who normally wear size 8 boots, found that they could not walk properly when wearing size 10 mukluks (two sizes larger than normal) and, although not satisfactory, preferred to wear the experimental duffel socks inside size 9 mukluks. It was found that during the longer test runs described below, this compromise resulted in considerable discomfort.

Experimental Procedure

In order to compare the thermal protection afforded by each type of duffel sock, it was decided to measure the temperature at several points on the feet of test subjects wearing both the standard and experimental duffel socks while in a cold environment. One of the important functions of the duffel sock is to absorb relatively large quantities of moisture resulting from foot perspiration. In cold-weather footwear the amount of moisture present and foot temperature are closely related. If the thermal insulation provided by one type of duffel sock is markedly different from that of the other, the warmer foot will produce a greater amount of perspiration. At the same time, if the moisture produced by the foot is excessive and remains in the duffel sock, the thermal insulation of the footwear will be reduced. It was thus decided that the evaluation should include a comparison of the amount of moisture absorbed by each type of duffel sock.

The evaluation was carried out to measure the variation with time of foot temperature and amount of perspiration produced by test subjects' feet when wearing the standard and experimental duffel sock. Test runs of 30, 60, 90 and 120 minutes duration were conducted with each subject participating in 4 runs at each time interval for a total of 16 runs per subject.

Prior to each test run, grey woollen socks, duffel socks and mukluks were weighed and each subject dressed in his Arctic clothing, excepting footwear. YSI Series 400 thermistor temperature probes were fitted at three different positions (great toe, mid-arch and ankle) on the left and right foot of each test subject. Subjects then donned the footwear. The standard and experimental duffel socks were worn on either the left or right foot, the position alternating from run to run.

The comparison was conducted in the DREO cold chamber at an ambient temperature of -23°C. Two subjects were used during each test run and they walked one behind the other on a level treadmill at 1.6 m $s^{-1}$ (3.5 mph) and facing a 4.5-m $s^{-1}$ (10-mph)wind. To equalize the effect of the wind, the subjects changed position every 15 minutes during a run. Foot temperatures

were measured only during the 120-minute trial periods and were recorded every 10 minutes, since similar information collected during the shorter runs would have been superfluous. At the end of each trial period, the test subjects came out of the cold chamber and removed their footwear. Grey woollen socks, duffel socks and mukluks were weighed immediately.

Between test periods, the components of the footwear systems were dried for at least 24 hours in a small chamber in the laboratory maintained at 25°C and low (<25%) relative humidity.

## RESULTS AND DISCUSSION

The evaluation was carried out in order to determine whether the durability, comfort and thermal protection offered by the experimental duffel sock were comparable to the level offered by the standard sock.

The durability of each sock was assessed by close visual inspection of each of the duffel socks regularly during the course of the investigation. Each of the eight duffel socks used (4 experimental and 4 standard) was worn for a total of twenty hours. After this period of time there was no noticeable deterioration in either the material or construction of any of the socks.

Since none of the test subjects could be fitted properly with the experimental duffel socks, it is impossible to comment meaningfully on the comfort provided by these socks based on the subjective experience gained during this trial. Especially during the longer test periods, chafing caused large blisters to form on the feet of some test subjects and they found that the duffel socks were extremely uncomfortable. For this reason the number of test runs originally planned for this evaluation had to be reduced considerably.

It should be emphasized that the discomfort was caused by poorly fitting footwear and not by the material itself. During the thickness measurements on the experimental wool/nylon and standard wool/viscose materials, it was observed that the wool/nylon was more compressible and more resilient than the wool/viscose. These properties, combined with the increased thickness (∿40%), should have made the experimental duffel more comfortable to wear than the standard one. However, it appears that the increased thickness of the wool/nylon material is at least in part responsible for the sizing difficulties and thus the discomfort experienced, i.e. the mukluk and the standard wool/viscose duffel sock of a particular size were designed to fit comfortably around a foot of that size. The wool/nylon sock is made of a double layer of material which is 40% thicker than the standard duffel. Since in any given case the foot and mukluk sizes remain the same, when the thicker experimental duffel sock is substituted into the combination, difficulties are inevitable.

The change in weight (moisture content) of each type of duffel sock after being worn by test subjects in the cold room at -23°C for periods of 30, 60, 90 and 120 minutes is given in Table III. Similar tables (not shown in this report) were also prepared using data from measurements of the change in weight of the grey woollen socks and mukluks worn during the same

test periods. Statistical analysis of each set of paired observations using the Student-Fisher t-test indicates that there is no significant difference ($p=0.005$) between the moisture content of either the standard or experimental duffel socks themselves or the other components of the mukluk assemblies when worn with either type of duffel sock.

Figure 3 is a graph of the mean change in weight versus time of each of the components of the standard mukluk assembly. This data confirms observations made in a previous study (3), in which it was found that the moisture content of the mukluk and grey woollen sock appears to reach a constant level after wearing for a relatively short period, but that the moisture absorbed by the duffel sock continues to increase with time. The total amount of perspiration produced by the test subjects' feet after exercising for 90 minutes in the cold on a treadmill is also in general agreement with previous findings. In the present study, moisture due to foot perspiration when wearing either the experimental or standard mukluk was not a cause for foot discomfort.

A comparison of the variation with time of mean foot temperature of the test subjects when wearing standard and experimental duffel socks on opposite feet during the 120-minute test periods in the cold chamber is given in Table IV. Each entry in the table represents the average of twelve measurements (temperature measured at three different locations on each foot x four test runs per subject). As discussed for the measurements of change in moisture content, there is no appreciable difference between the temperatures of the feet of the test subjects when wearing either the experimental or the standard duffel sock.

Initially, in each case, mean foot temperature increased a few degrees after the subjects started to march on the treadmill. Within 30 minutes after starting, foot temperatures reached a nearly constant level of about 34°C. Subjectively, the test personnel felt that their feet were not excessively warm or cold, i.e. under continuous exercise both types of duffel socks act to maintain the feet at a comfortable temperature. It is interesting to note that the subject-to-subject variation in foot temperature (indicated by standard deviation in Table IV) also decreased to a nearly constant level during the test period. The coefficient of variation (=standard deviation divided by mean) of the data decreased with time from $\sim$8% to $\sim$2%.

TABLE III

A Comparison of the Moisture Absorbed by Each Type of Duffel Sock

| SUBJECT | Moisture Absorbed (g) After Wearing For | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 minutes | | 60 minutes | | 90 minutes | | 120 minutes | |
| | STD* | EXP* | STD | EXP | STD | EXP | STD | EXP |
| 1 | 9.4 | 9.8 | 12.7 | 13.0 | 14.7 | 13.7 | 20.7 | 21.2 |
| | 5.9 | 5.6 | 13.4 | 14.1 | 11.1 | 11.9 | 18.3 | 18.3 |
| | 3.9 | 4.6 | 9.0 | 9.1 | 13.1 | 13.5 | 19.3 | 19.5 |
| | 7.6 | 7.7 | 11.4 | 12.0 | 17.6 | 16.8 | 15.7 | 16.5 |
| 2 | 6.2 | 5.5 | 11.0 | 11.9 | 9.4 | 11.1 | 12.3 | 13.4 |
| | 2.5 | 3.3 | 11.6 | 11.5 | 9.5 | 8.0 | 9.8 | 11.4 |
| | 3.5 | 3.1 | 6.6 | 8.0 | 7.2 | 8.1 | 7.5 | 8.7 |
| | 5.5 | 5.4 | 7.8 | 7.9 | 10.0 | 9.8 | 9.3 | 8.1 |
| 3 | 5.7 | 5.2 | 13.0 | 12.4 | 20.8 | 20.3 | 31.1 | 27.1 |
| | 6.4 | 7.2 | 14.0 | 14.0 | 19.8 | 19.3 | 24.5 | 25.3 |
| | 5.7 | 5.6 | 15.0 | 14.6 | 19.1 | 20.0 | 22.7 | 23.0 |
| | 5.7 | 6.3 | 14.2 | 15.0 | 19.1 | 19.7 | 30.4 | 24.5 |
| 4 | 6.4 | 6.6 | 11.1 | 12.5 | 20.6 | 21.8 | 22.3 | 20.2 |
| | 9.3 | 9.5 | 15.2 | 16.0 | 15.9 | 16.6 | 24.3 | 23.0 |
| | 3.4 | 2.8 | 16.0 | 15.7 | 19.1 | 21.1 | 19.2 | 19.7 |
| | 8.8 | 8.5 | 15.4 | 14.5 | 18.4 | 18.8 | 15.0 | 22.3 |
| mean | 6.0 | 6.0 | 12.3 | 12.6 | 15.3 | 15.7 | 18.9 | 18.9 |
| std. dev. | ±2.1 | ±2.1 | ±2.8 | ±2.5 | ±4.6 | ±4.8 | ±7.1 | ±5.8 |

* STD = standard duffel sock
EXP = experimental duffel sock

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TABLE IV

Average* Foot Temperature (°C) as a Function of Time in Cold Chamber at -23°C.

| | Subject No. | TIME (minutes) 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard Duffel | 1 | 29.7 | 30.8 | 33.2 | 34.4 | 35.0 | 34.7 | 34.9 | 34.1 | 34.1 | 34.3 | 34.0 | 33.7 | 33.8 |
| | 2 | 28.1 | 28.5 | 29.7 | 31.4 | 32.7 | 33.1 | 33.6 | 32.8 | 33.2 | 33.7 | 33.6 | 33.6 | 33.7 |
| | 3 | 31.1 | 33.1 | 34.4 | 34.7 | 34.9 | 34.8 | 34.8 | 34.1 | 34.4 | 34.4 | 34.5 | 34.5 | 34.3 |
| | 4 | 32.4 | 33.0 | 34.2 | 34.5 | 34.6 | 34.4 | 34.4 | 33.9 | 34.2 | 34.1 | 34.2 | 34.2 | 34.2 |
| | mean | 30.3 | 31.3 | 32.9 | 33.7 | 34.3 | 34.3 | 34.4 | 33.7 | 34.0 | 34.1 | 34.1 | 34.0 | 34.0 |
| | std. dev. | ±2.1 | ±2.4 | ±2.3 | ±1.7 | ±1.2 | ±0.9 | ±0.8 | ±0.8 | ±0.7 | ±0.7 | ±0.6 | ±0.6 | ±0.5 |
| Experimental Duffel | 1 | 30.3 | 31.4 | 33.5 | 34.6 | 35.3 | 35.0 | 35.3 | 34.5 | 34.7 | 34.7 | 34.8 | 34.5 | 34.6 |
| | 2 | 27.4 | 28.1 | 29.3 | 30.6 | 32.0 | 32.8 | 33.4 | 33.0 | 33.0 | 33.5 | 33.6 | 33.6 | 33.7 |
| | 3 | 30.7 | 32.7 | 34.5 | 35.0 | 35.1 | 35.0 | 35.0 | 34.2 | 34.5 | 34.5 | 34.6 | 34.6 | 34.5 |
| | 4 | 32.7 | 33.5 | 34.5 | 34.7 | 34.9 | 34.6 | 34.7 | 34.0 | 34.2 | 34.1 | 34.3 | 34.3 | 34.3 |
| | mean | 30.3 | 31.4 | 33.0 | 33.7 | 34.3 | 34.4 | 34.6 | 33.9 | 34.1 | 34.2 | 34.3 | 34.3 | 34.3 |
| | std. dev. | ±2.3 | ±2.5 | ±2.7 | ±2.3 | ±1.3 | ±1.3 | ±1.0 | ±0.8 | ±0.9 | ±0.7 | ±0.7 | ±0.6 | ±0.6 |

* each entry in the Table represents the average of 12 measurements (4 runs per subject X foot temperature at 3 locations)

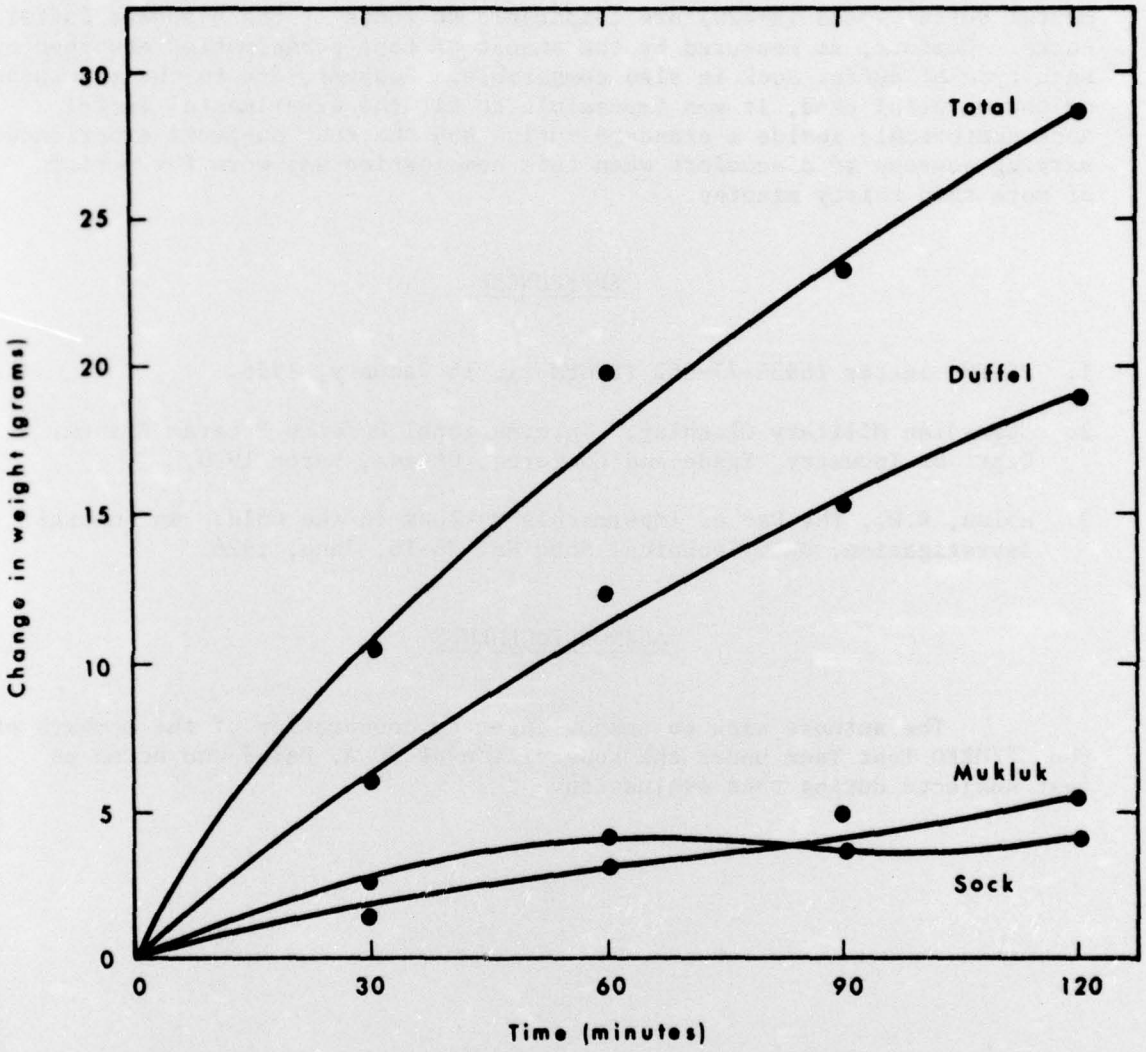


*Fig. 3 - Mean Variation with Time of Weight of Components of Mukluk Assembly*

## CONCLUSIONS

As a result of the evaluation described in this report it is concluded that the durability and thermal protection offered by the experimental duffel socks (B-429) are comparable to those of the standard duffel socks. Comfort, as measured by the amount of foot perspiration absorbed by each type of duffel sock is also comparable. However, due to the thickness of the material used, it was impossible to fit the experimental duffel sock comfortably inside a standard mukluk and the test subjects experienced varying degrees of discomfort when this combination was worn for periods of more than thirty minutes.

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A series of physiological trials was conducted in the DREO cold chamber to compare the durability, comfort and thermal protection offered by the standard Canadian Forces duffel sock and an experimental duffel sock worn with the Arctic mukluk. No significant differences in levels of foot perspiration or foot temperature were observed. However, since the correct sizes were not available, none of the test subjects could be fitted properly with the experimental duffel sock and varying degrees of foot discomfort were experienced.

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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.